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Recommendations for the management of leafy spurge in Theodore Roosevelt National Park

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Leafy Spurge Scientific Advisory Panel

Theodore Roosevelt National Park selected an advisory panel composed of university and federal agency scientists to develop recommendations for the management of leafy spurge. Below are listed the panel members and their current affiliation.

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United States Department of the Interior
National Park Service
Theodore Roosevelt National Park
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January 13, 1995

Dear Interested Party:

Enclosed is a copy of the Recommendations for the Management of Leafy Spurge in Theodore Roosevelt National Park. This report was prepared by a scientific advisory panel of interdisciplinary experts. The panel was asked to evaluate management alternatives and to provide recommendations for implementing a long-term management program to control leafy spurge that were consistent with National Park Service and Forest Service management policies, guidelines and legal mandates. Alternatives were evaluated based on environmental sensitivity, safety and effective integrated pest management (IPM) techniques. Previous research in the park and management actions were evaluated. The recommendations have applications for the park and adjacent public and private lands. How successful the plan will be depends on funding, staffing, and local cooperation.

Management actions are necessary to mitigate loss of habitat as a result of exotic infestations. Theodore Roosevelt National Park will consider the panel's recommendations and strategies by preparing an Environmental Assessment (EA). This noxious weed knows no jurisdictional boundaries. Through joint cooperative efforts a plan can be developed for managing different levels of infestation within identified watershed basins.

We appreciate your interest in the Park's approach to managing this aggressive exotic plant. Should you require more information please contact Roger Andrascik, Resource Management Specialist at (701) 623-4466.

Sincerely,

Bruce M. Kaye

Acting Superintendent

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Preface

A leafy spurge management workshop was held in Dickinson, North Dakota, on March 29 and 30, 1994, to address the issue of leafy spurge management in Theodore Roosevelt National Park (TRNP). The workshop was prompted by rapid expansion of leafy spurge within TRNP and the immediate need to develop an effective integrated pest management approach that could be incorporated into the Park's overall management plan. The workshop brought together experts on the biology and physiology of leafy spurge, biological and chemical control of leafy spurge, and remote sensing and geographic information systems. The purpose was to provide the most current information on tools available to assess and quantify the current status of leafy spurge in the park and methods to control and manage its expansion.

A scientific advisory panel also participated in the workshop to receive current information and to develop a leafy spurge management plan for the Park. The panel met for one day following the workshop to draft the recommendations contained in this report. The panel was reconvened at the Park on May 25 and 26 to observe problem areas and continue discussions on management approaches. The advisory panel consisted of Russell Lorenz and Edward Redente, who co-chaired the panel and Robert Carlson, Rodney Lym, Calvin Messersmith, Chuck Quimby, Kevin Sedivec, and Linda Wallace. Because of the need to address the use of fire as a management tool for controlling leafy spurge, Carolyn Hull-Sieg was invited to participate on the panel following the workshop in March.

The following are the panel's recommendations for managing leafy spurge in TRNP. These recommendations represent our best understanding of this species and the best management practices to date. It is important to recognize that the technology associated with control of pest species such as leafy spurge is ever changing and the management plan developed must be dynamic and evolve over time as the technology changes and as the need within the Park is altered through human manipulations and natural ecological processes.

Introduction

Leafy spurge (*Euphorbia esula*) is one of the most aggressive and troublesome plants in the western United States. Of the approximately 2.5 million acres infested with leafy spurge, more than half are in North Dakota and Montana. Leafy spurge occupies a broad ecological range of habitats, from xeric to subhumid, and from subtropical to subartic. It will tolerate flooding over periods of at least four to five months, provided the shoots can grow above the water surface. Although leafy spurge frequently becomes established in moist places, it also is well adapted to dry, upland sites and shallow, rocky soils. Leafy spurge grows in nearly all soil types, but appears to favor coarse textured soils.

The aggressiveness of leafy spurge can be related to its phenomenal ability to spread by producing horizontal roots, to propagate by producing buds profusely, and thus, to establish long-lived dense infestations. Leafy spurge seedlings growing without competition

develop roots that can penetrate to a 3-foot depth in four months and attain a lateral spread of 40 inches. Leafy spurge's deep root system allows it to survive without top growth for five or more years. Stems originating from crowns of leafy spurge begin growth in April, making it one of the first plants to emerge in the spring. This early and rapid growth helps give this species its competitive advantage over most other plants.

Seed yield from leafy spurge patches has been calculated to range from 24 to 2,400 pounds per acre. When the capsules that contain seeds dry, they dehisce explosively and distribute the seed fairly uniformly from 1 to 13 feet from the plant. The ability of the seed to float and germinate in water is an advantage for spurge establishment in areas that occasionally flood.

Leafy spurge seeds remain viable in the soil for as long as 8 years. Large seed reserves in the soil, coupled with seed dormancy and a phenomenal ability to emerge from deep roots enables an established stand of leafy spurge to survive repeated control attempts.

There also have been some reports that leafy spurge may be allelopathic to other plants under laboratory conditions. Allelopathy also is suggested by the small number of forbs in leafy spurge patches, even when bare ground is visible between shoots.

Leafy spurge is a serious problem in TRNP and its invasion has resulted in the disruption of native plant communities and is threatening the survival of several rare plant communities (Figure 1). In addition, leafy spurge has no forage value to the large native ungulates in the Park and its presence is therefore reducing the carrying capacity of the area.

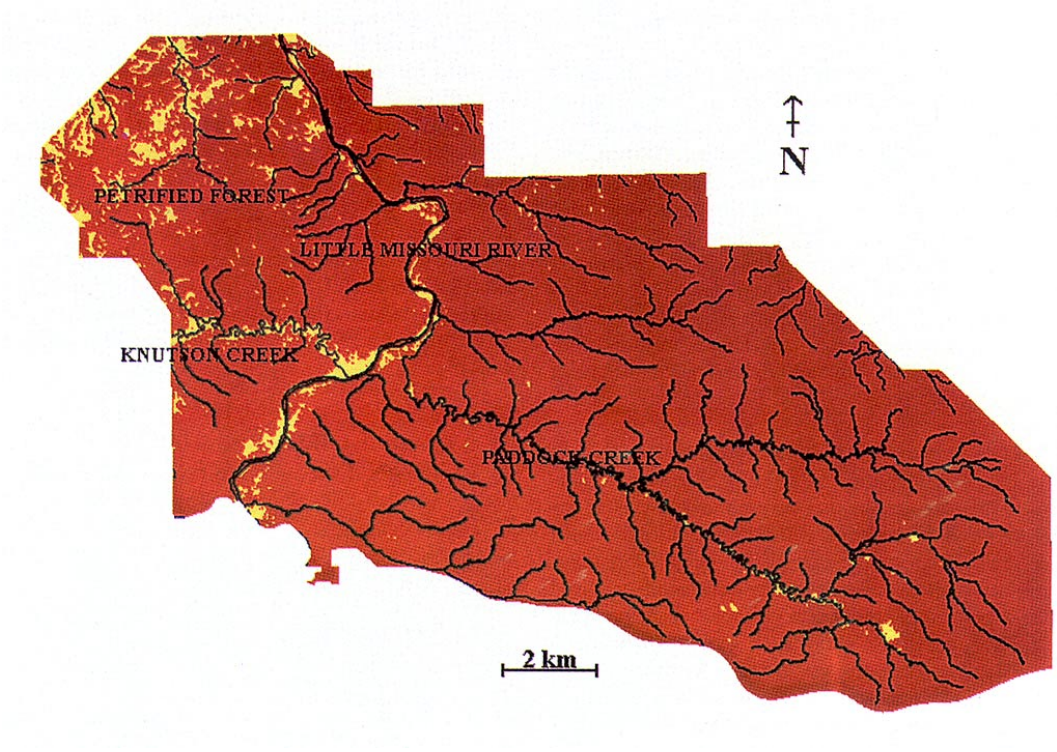

Figure 1. Map of leafy spurge infestations, shown in yellow, within Theodore Roosevelt National Park.

Leafy spurge was brought into North Dakota by Eastern Europeans during the Homesteading Period. Locally, leafy spurge originated west of the Park in Golden Valley County along Knutson Creek during the 1930's. Leafy spurge was first reported in the Park in the late 1960's.

In 1970, park managers estimated that there were 32 acres of leafy spurge infested, divided into 103 separate patches ranging from a few square meters to three acres. In 1971, Tordon was placed on the restricted use list and the National Park Service did not authorize its use. As a result of fiscal cutbacks, the Park eliminated leafy spurge control from the 1971 program. Leafy spurge control began in the Park in 1975 and currently consists of limited herbicide applications and a biological control program in cooperation with the Animal and Plant Health Inspection Service, Agricultural Research Service, North Dakota Department of Agriculture, and North Dakota State University. Between 1975 and 1983 the infestation was estimated at 400 acres. In 1986, 700 acres was considered a conservative estimate of leafy spurge in the Park. Base funding levels treated less than 10% of the estimated 800 acres in 1991. The exotic plant crew has not been funded since 1992 for ground-hand application.

The success of chemical control has been limited because of limited resources, difficult access in the backcountry, and the existence of a designated wilderness. The biological control program is limited to a small scale at the present time and the ability to use this approach on a large scale is a hope for the future. The Park has recently used a micro-foil boom helicopter for spraying larger acreages in areas of difficult access. This approach to chemical spraying is highly specialized and uses a boom capable of precise targeting of chemicals with virtually no chemical drift. However, the use of helicopters is very site specific and not suitable for all situations. An Integrated Pest Management (IPM) approach is being proposed by the Park over the next 10 years to include such methods as chemical treatment, biological agents, mechanical methods such as mowing, and prescribed burning in conjunction with chemical treatment.

In addition to the concerns listed relative to chemical control, other concerns have also hampered the widespread use of herbicides that are not highly selective for leafy spurge. Concerns about the loss of woody plants and non-target forb species are of special issue in a National Park. These losses are of direct concern, in that riparian cottonwood communities, woody draws, and Rocky Mountain juniper stands are highly important wildlife communities in the Park. For example, the vast majority of nesting bird species are found in the riparian and woody draws. Loss of woody vegetation means the loss of critical habitat that is difficult to re-establish. Further, many native wildlife species rely on a variety of forages that include woody plants and forbs. Less well understood impacts include those on various small mammals, insects, and other native vertebrates and invertebrates. In addition, high costs, concerns about ground water contamination, and the fact that herbicides do not kill leafy spurge plants have further restricted the use of herbicides in the Park.

Therefore, in keeping with the philosophy of managing a National Park, the leafy spurge management plan should stress a long-term strategy that makes the protection and enhancement of native plants and animals of utmost importance. Short-term solutions that create other problems should be avoided. Further, the Park should do their best to rein-

state those disturbance factors (e.g. fire) that existed historically, as these factors play a vital role in the perpetuation of Northern Great Plains ecosystems.

Objectives

The primary objective that the panel was asked to address in its recommendations is: develop management strategies that will restore and insure perpetuation of native plant communities, without further degradation of habitat, or impact to other sensitive resources from leafy spurge within TRNP. Secondary questions that the panel was asked to address are listed below:

- What are the potential short-term and long-term impacts to the ecosystem from a range of alternatives, including the no action alternative to the preferred control alternative?
- What are the environmental consequences of the preferred control alternative and its implications to the ecosystem?
- Can large infested acreages of leafy spurge be reduced without adversely impacting other components of the ecosystem?
- What are the probable impacts of the leafy spurge infestation and its control measures on locally sensitive, rare, threatened, or endangered plant/animal species?
- What long-term monitoring protocols and research should be developed to evaluate control effectiveness and the potential impacts to biotic/abiotic resources and public health from the preferred control alternatives?
- Should other IPM methods for control of leafy spurge be considered?

The recommendations that follow are divided into several categories associated with chemical control, biological control, livestock grazing, fire, and a general category that addresses remote sensing, GIS, public education, and preventative actions that can be taken by the Park.

Chemical control

Recommendations are restricted to the South Unit of the Park since the major concern about infestation and control have been focused on this part of the Park. However, it is important not to ignore the North Unit that is relatively free of leafy spurge at this time. It is critical that development and implementation of a control and management program must include the basic concept that areas of the Park that are free from leafy spurge now, should be kept free of leafy spurge in the future. A plan that manages or controls leafy spurge in one area, as the species simultaneously establishes in other areas will be ineffective.

The following recommendations are listed in priority of implementation.

1. The smaller infestations in the south Paddock Creek area should be controlled with high rates of picloram (> 1 lb/A) to prevent the now isolated infestations from joining into another large area such as in the Petrified Forest area. The maximum use rate of picloram is 2 lb/A and should be used as much as possible on the small (< 1 A) infestations. There are two reasons for the high rate: 1) to gain 90% or more control immediately, thus preventing spread; and 2) to avoid having to pay for helicopter time over the same small areas every year.

The maximum labeled use rate may not be applicable in all areas with small patches. The depth to ground-water and potential for runoff and thus movement into surface water must be considered. However, the dilution factor is large when spraying small patches in a large area so the same potential for contamination is small compared to spraying high rates over the entire area.

2. On the larger areas of the South Paddock Creek area, a 3- to 5-year chemical control plan should begin. The herbicides to use include picloram plus 2,4-D at 0.5 + 1 lb/A in areas where streams or ground water-table is not a concern. Expect about 85% control after 3 years. A second option is glyphosate plus 2,4-D at 0.4 + 0.6 lb/A applied in late June or early July. Control will be about 70% the next year. The follow-up treatment must be picloram + 2,4-D at 0.25 + 1 lb/A, because glyphosate applied in two successive years will damage grasses. It is critical that the application of glyphosate plus 2,4-D be properly calibrated to prevent injury to grasses. An alternative treatment approach would be to alternate between glyphosate plus 2,4-D and picloram plus 2,4-D, with glyphosate plus 2,4-D applied in years 1 and 3 and picloram plus 2,4-D applied in years 2 and 4.

Along the stream itself, we recommend Rodeo plus 2,4-D (using a 2,4-D formulation that is labeled for water) in mid to late July to begin reducing the infestation. Expect about 70% control the following year with this treatment. If erosion or bareground is a concern, then use 2,4-D (labelled for use in water) at 1 to 2 lb/A annually. The 2,4-D treatment will not reduce the original infestation but will keep it in check.

In small areas, fosamine (Krenite) at 6 to 8 lb/A could be used up to the waters edge, but this is an expensive treatment. Expect about 80% control with this treatment one year after application.

3. Moving north into the Little Missouri River and Knutson Creek area, the infestations are much more dense and well established. These areas (excluding riparian areas and woody draws) will require annual applications of picloram plus 2,4-D for at least 5 years before achieving 85% or more control. If monies are available, this treatment should begin in 1994. However, if chemical treatments cannot begin in 1994, then this area would be best served by a non-chemical approach such as grazing or biocontrol agents.

The minimum annual treatment should be to treat the edges along the infestation. This will limit the spread of leafy spurge into non-infested land.

4. We recommend that the areas treated by helicopter in 1993 continue to be treated for two additional years. This recommendation is contrary to the concept of treating the small areas first and then moving into the large ones. However, if these treatments are not continued, the infestation will reestablish within 12 months and the previous effort will

be wasted. By continuing treatment, the Park will be able to demonstrate that herbicides can be effective. In addition, in-roads will be made on some of the most dense areas in the Park that can be expanded upon in the future.

If there are critical areas within the Petrified Forest for plant or animal habitat, these areas should be kept free of leafy spurge. This could be accomplished by treating the edge of the infestations nearest the critical area. The area would need to be monitored for new infestations that might cross this boundary.

General Comments. The new worker protection standards are very clear about posting and reentry. Since rangeland and roadsides are exempt it should not be a major concern. Obviously, that portion of the Park scheduled to be sprayed should be closed the day of and possibly the day after spraying.

Because of concerns about the loss of woody vegetation from herbicide spraying, research needs to be conducted on methods for setting back leafy spurge without killing woody plants and non-target forbs. Efforts to explore the use of herbicides that are highly selective for leafy spurge should be made. Herbicides should be evaluated based on a matrix which includes movement in the soil, movement in ground water, half lives, mammal toxicity, selectivity for leafy spurge, and cost, in addition to effectiveness.

Water samples should be collected from streams and ground-water at the end of each season to be sure picloram is not contaminating the water. Collections should also be made from non-treated areas to provide a control sample.

Permanent vegetation sample points should be established in treated and nontreated areas regardless of the control method. The recommended protocol is as follows: A total of two 25 m transects should be established and permanently marked on each treatment site. Two additional 25 m transects should be established on an adjacent untreated site. Before treatment and for at least 2 years post-treatment, plant canopy cover should be estimated in 25 0.1 m^2 (20 × 50 cm) quadrats spaced at 1 m intervals on each transect. Species to be recorded should include at least leafy spurge, but data on non-target plant species would also be valuable. Cover should be estimated to fall into one of six cover classes according to methods outlined in Daubenmire (1959). In addition, numbers of leafy spurge plants should be counted in a minimum of 10 0.1 m^2 quadrats per transect, and recorded as vegetative or flowering. In an effort to standardize the timing of the sampling, it is recommended that all pre- and post-treatment sampling be conducted at the time of peak production. This usually occurs about mid July, but will vary from year to year depending upon climatic conditions. Photo points should also be established and used regularly in the monitoring process.

The current pesticides listed for use in the park are the best options available with a few exceptions. Consider using clopyralid instead of dicamba or picloram for Canada thistle control. It is the best herbicide available for thistle control and it has less residual than either picloram or dicamba.

None of the herbicides labeled for leafy spurge control are of special concern to wildlife or people. The LD_{50s} are very high (i.e. low toxicity) and they do not build-up in the food chain. The greatest concern is to prevent picloram from moving into the surface or

ground-water. The half-life for picloram in North Dakota is about 13 months. However, once picloram enters the ground-water it is long lived.

Our estimate is that it would cost approximately $64,000/year to treat the present 1600 acres with picloram plus 2,4-D at 0.5 + 1 lb/A (including helicopter time). After 3 to 5 years, the infestation would be reduced, but 1600 acres would still exist. The leafy spurge patch expansion equation is provided below and is a useful tool to calculate how quickly leafy spurge will expand in the future.

Leafy spurge patch expansion formula (For patches at least 4 years old)

$X = \pi*[(Y-4)* 2\ ft^2]$

$Z = X * (10\ stems\ /ft^2)$

where Y = years

ft = feet

X = area of patch in square feet

Z = total stems in patch

This is a simple formula but fairly accurate for as easy as it is to use.

Biological control

The following is a discussion of short and long-term impacts and the environmental consequences of control alternatives (biocontrol agents) and their implications for TRNP:

Introduction of Insects (classical biological control) – Regarding impacts, this approach should not be considered a short-term answer to the leafy spurge problem. However, in the long-term, this approach where successful, would be expected to reduce the incidence of leafy spurge to acceptable densities consonant with the management goals of the Park. Regarding implications to the ecosystem, this approach, if successful, should provide for near-restoration of native plant communities. Unsuccessful introductions could cause a delay in implementing other control measures. To reduce that risk, alternative control methods, e.g. chemicals, could be employed around perimeters of large stands to prevent expansion of leafy spurge from those areas where relatively non-mobile species of insects, e.g. leafy spurge flea beetles, have been released.

Introduction of pathogens (classical biological control) – This approach is as safe as the introduction of insects provided that proper host testing is done. However, this method for leafy spurge control is still in the early research stage and cannot be recommended at this time.

Augmentation of native plant pathogens – The panel recognizes that this approach with plant pathogens already extant in the Park would be a preferred method, i.e. the pathogens would be found in the Park, isolated, characterized, cultured, formulated, and delivered back to the Park. In this way, nothing new would be introduced. If this approach were deemed ineffective or inappropriate, then the practice could be discontinued and the organism(s) would revert to their original status. This approach might be appropriate, if successful, as a "spot" treatment for small outlying stands in environmentally sensitive areas where chemicals cannot be used. Or the pathogens might be used in conjunction with low dosages of chemicals that might interfere with protective mechanisms in leafy spurge. This approach is still in the research and development stage and no recommendations can be made at this time.

Effects of biocontrol agents on native *Euphorbia* species – Agents have been screened against *Euphorbia* of commercial importance and *Euphorbia* identified as threatened or endangered (using closely related species). No endangered *Euphorbia* species have been identified in the 1990 inventory of rare plants of southwestern North Dakota. *Euphorbia robusta*, which has been identified as "a critically imperiled" native plant species in the Park, has been one of the test species in the screening process for some, but not all, of the leafy spurge biological control agents. See Appendix for further information on this topic.

General recommendations

Areas should be designated in the Park where insect biocontrol agents are to be established. Park resource managers in cooperation with researchers should then prioritize sites for insect releases. For example, woody draws, riparian zones, and juniper stands should be designated as high priority release sites, if the conditions are proper for one or more insects species. Consideration should be given to habitat requirements of individual species, objectives for management of various parts of the Park, and possible conflicts with other management strategies.

Biological control is not appropriate for those areas where complete elimination of leafy spurge is desired. It is also not appropriate where containment is the objective; biological control does not stop the spread of a target species, although it may greatly retard the rate of expansion. If biological control is successful, the target species will be a minor member of the plant community wherever it occurs. Isolated patches are not recommended for insect release but may be appropriate for augmented pathogens, when available. Insect releases in large area infestations should allow for perimeter containment of leafy spurge by other methods. Releases on flood plains (areas that are susceptible to seasonal flooding) should be avoided. Because of the long term nature of biological control efforts, the primary consideration in release of any agent should be the potential for successful establishment. If an agent is effective, it should, over the long-term, find its own areas of adaptation.

For biological control to be effective, field insectaries must be established and appropriate locations need to be selected where excess adult insects can be collected for redistribution.

Aphthona spp. – Proper management of release sites will provide functional insectaries for internal Park purposes. Monitoring of population increases and judicious harvesting and movement of excess adults to new locations on an annual basis is recommended after vigorous insect populations and leafy spurge reductions are evident at a release site. Movement of insects should be done after some oviposition has occurred at the originating site but before the females have expended a significant portion of their eggs (i.e. 2 to 3 weeks after emergence of the adults). Acceleration of wide-area impact, i.e. reduction of leafy spurge density in a large infestation, is a current topic of research. Preliminary data suggest that movement of insects in smaller numbers (e.g. 150) to numerous release points may provide more rapid attainment of sub-economic leafy spurge density than a single release of large numbers of insects.

Oberea spp. – For insectaries, these agents should be placed where stem diameters are adequate to support larval development (estimated 3 to 4 mm). Normally, the large-stemmed spurge occurs in the sites with higher moisture and/or shade. Reproductive rates of *Oberea* spp. however are slow, and it may take many years for populations to build up for harvest and redistribution.

Other species – As other species become more available, Park personnel should consult with research agencies regarding insectary and redistribution considerations.

The total number of agents, by species, that are recommended for the control effort is an important concern but not easily answered. In general, the more agents that can be released, the more rapidly acceptable density levels of leafy spurge can be achieved. Preferred sources are state and federal agencies involved in biological control efforts. Insects released should be free of disease and properly identified.

The use of biological control agents should include monitoring as an integral and necessary component. We recommend that monitoring of biological control agents be designated as a high priority within the Park. To evaluate the effectiveness of the agents, baseline (pre-release) data on leafy spurge density should be taken using uniform ecological sampling techniques when practical. In all cases, follow-up sampling should be done yearly. Monitoring recommendations for plant responses that are presented under the Chemical Control section also apply here.

Finally, the need for research to continue the advancement of our understanding of biological control and to develop new agents cannot be over emphasized. The following suggestions address the areas of research that we believe are most important at the present time.

1. Refinement of descriptions of habitat requirements for individual insect species.
2. Evaluation of integrated management systems for optimal efficacy of control agents.
3. Survey for and development of extant native pathogens for “spot” treatments in environmentally sensitive areas.
4. Development of optimal release strategies for new agents (e.g. clearwing moth species and other foliage feeding species) as they become available.

5. Evaluation of interactions that may occur among biological control agents (insects or pathogens), other control methods, and the environment.

Livestock grazing and mowing

The panel recognizes the potential problems associated with introduction of domestic livestock into the Park for leafy spurge control. The risk of spreading diseases to native ungulates is real and the potential threat is serious. Therefore, the panel recommends that further study be implemented to address the issue of disease transmittal. If the issue of disease can be answered to the satisfaction of resource managers in the Park, and disease-free livestock can be obtained, we recommend that grazing be used as a management tool according to the following recommendations.

1. Those leafy spurge infestations along the Little Missouri River starting near Mike Auncy Flowing Well and following the river to the south throughout the drainage and those areas along the Knutson Creek drainages could be considered for grazing as a management practice. These areas have a water quality concern and are heavily wooded. These areas also have easy access for introduction of goats or sheep. Although rare plants occur in these drainages, from the information that we have, there appears to be little overlap with the leafy spurge infestations at this time. Grazing in these areas would provide a useful tool for minimizing seed production and spread of leafy spurge. Insect release sites could be established in conjunction with grazing in these areas to provide long-term control.

2. The area in the northwest portion of the South Unit of the Park has rugged terrain and poor access. Grazing could be used in this area, but because of the difficulties with terrain, access, and the risk of depredation by coyotes, we recommend against the use of livestock in this area of the Park.

3. A fall-applied herbicide treatment is also recommended in combination with the grazing treatment. NDSU research has shown that the combination of the two methods provides much better control in a shorter time than either method alone.

4. Goats appear to be more effective in controlling leafy spurge than sheep. The one disadvantage of goats is that they will selectively feed on woody plants and may have a negative effect on these species. Goats are less prevalent in North Dakota than sheep, but goats tend to have less disease problems than sheep.

5. Stocking rates for sheep and goats are recommended at 3 to 4 goats or sheep per acre of leafy spurge. Grazing should occur during the period of mid-May through June and again in the fall, in order to stress plants prior to the winter months. Grazing must be continued over time to keep leafy spurge under control. We recommend that local producers be contacted to provide animals as opposed to the Park purchasing livestock. Herding of the animals would be mandatory for both sheep and goats and logistical problems associated with protection from predators.

In addition, animals should be closely screened to avoid introducing diseases that can be detected, and ewes in estrus may have to be removed from the Park to prevent contact with bighorn sheep. Finally, some consideration should be given to the sociological im-

pacts of using goats or sheep in the Park. Some visitors may be disturbed to see domestic animals in the Park and this issue should be addressed before implementing a grazing plan.

6. Mowing has not been shown to control leafy spurge when used alone or with another control method. Mowing will prevent seed-set but does not reduce the original infestation. The use of mowing in campground areas could be continued to reduce the spread of the plant by seed. However, if the release of sap from the mowed plants becomes a public health concern, this management approach should be discontinued in campground areas.

Use of fire

Due to leafy spurge's ability to sprout following fire, burning cannot be viewed as a panacea for control of the spread of this plant. However, recent data suggest that fire may reduce germination rates of leafy spurge seeds, and may also be used in conjunction with other methods to discourage the expansion of leafy spurge patches. Research conducted near the Park evaluated prescribed burning and herbicides alone, or in combination, as methods for slowing the expansion of leafy spurge. A spring burn with or without a fall herbicide application was the most effective treatment for reducing leafy spurge seed germination. Herbicides with or without burning were most effective in reducing leafy spurge stand density. Picloram plus 2,4-D applied in the fall followed by spring burning provided the best control of leafy spurge density and reduction of seed germination in this area.

Fire may also be used in other ways to attack the leafy spurge problem. For example, fire can be used to encourage sprouting. This functions to both reduce carbohydrate reserves in the leafy spurge plants and to achieve relative uniformity in the phenological development of the plants. Follow-up herbicide treatments are more likely to be effective, in addition to reducing the germination rates of seeds. Second, fire might also function to weaken plants and make them more susceptible to not only herbicides, but also to insects.

The introduction of fire into TRNP is also important from the viewpoint of maintaining vigorous native plant communities. In the Park's effort to maintain healthy, functioning ecosystems, it is necessary to retain not only all of the native plant, animal, and invertebrate components, but also the historical disturbances such as fire and flooding that played integral roles in the maintenance of these systems. Although data on the historical fire frequency in the Park are not available, and Park records indicate the rarity of large-scale burns since 1947, data from other areas in the region suggest that both lightning and American Indians set fires on a regular basis. In the Slim Buttes area south of the Park, an average of six lightning fires occur each year. These fires may be ignited anytime during the growing season, but are most likely to occur in July and August.

A survey of historical documents, including journals of early Euro-Americans traveling through the Northern Great Plains region, combined with interviews with American Indians, indicated that Indian-set fires occurred on a regular basis. Although fires were likely in any month, none were noted in June or January, and peak numbers of fires set by American Indians occurred in the spring and fall.

The consequence of relatively frequent fires, whether ignited by lightning or humans, was that plants and animals developed adaptations to burning. Fires functioned to rejuvenate decadent plants, enhance decomposition rates, make nutrients available for plant growth, influence the use of the vegetation by large herbivores such as bison, and enhance the forage quality for species such as white-tailed deer, etc. Periodic small scale burns also consume fuels and thus make larger scale catastrophic fires less likely.

Deciduous woody plants are examples of species that commonly respond positively to burning. The ability of these species to resprout vegetatively makes them able to survive or even expand when top-killed by fire. Many of the common woody species occurring in the Park, including chokecherry, snowberry, and wild plum are strong sprouters following fire. In most years, prairie fires probably skipped over or only burned lightly through woody draws. However, the narrow configuration and close contact of these woodlands with flashy grassland fuels suggest that historically woody draws were exposed to a high number of grassland fires that would inevitably enter the woodlands, especially in dry years on hot and windy days. Recent research in the Black Hills and Badlands National Park indicates that fires show promise in rejuvenating decadent woody draws. Following fall burning, numbers of sprouts of green ash and chokecherry increased.

General recommendations

There is a need to assess the historical fire frequency and timing in the Park. There is also a need to develop a burning plan that approximates the historical role of fire in the Park. Prescribed fire should be introduced in the Park on a small, experimental basis, and on a larger system scale. Small experimental burns should be used to assess the feasibility of using a combination of fire and flea beetles in woody draws to both stimulate woody vegetation and reduce leafy spurge. Research should test hypotheses about using fire to set up plants for pathogens, insects, and herbicides. Research should also examine the role of multiple fires in setting back leafy spurge and the mechanisms involved in the influence of fire on leafy spurge seed germination.

There is also a need to better understand the role of fire in the evolution of leafy spurge, microhabitat requirements of leafy spurge, and specific mechanisms involved in the germination process. The introduction of fire on a larger scale is important from the viewpoint of maintaining healthy, functioning ecosystems. The mandate of the Park is to not only preserve the native biotic components of the area, but also to allow those disturbances that occurred historically to continue. The importance of disturbances such as fire in the maintenance of native Northern Great Plains communities is generally not fully understood, but initial data suggests that fire plays an integral role in the ecology of these communities.

Other considerations

This section addresses issues that, for the most part, do not fit within any of the previous topics discussed and for convenience are presented in this one section.

1. Because of the serious infestation of leafy spurge on lands adjacent to the western boundary of the Park, it is imperative that a regional plan for management of leafy spurge in the Park and on adjacent lands be developed and implemented.

2. A high priority for treatment is to keep clean land clean and contain spread in areas of greatest threat, such as critical habitat for wildlife, rare plants, woody draws, and riparian areas.

3. There needs to be a working GIS system within the Park rather than a dependency upon other federal agencies. The Park should develop a plan for conducting contingency analyses to examine relationships between the distribution of leafy spurge and such factors as soil type, slope, aspect, land use history, current land use by native ungulates, presence of "vulnerable" ecosystem aspects such as rare plants, riparian habitats, and potential for disease transmission to native ungulates. This information would be extremely valuable in both the development and amendment of the overall management plan, for educating the public, and in securing public and financial support for leafy spurge control. The presence of leafy spurge in the North Unit should be digitized using ground data and entered into the GIS system.

4. Ground truthing needs to be conducted to verify remote sensing data. Ground truthing should include ground level photography, permanent photo points, and permanent vegetation transects to document change over time. Sites should be characterized and prioritized based on categories such as: 1) open land that is infested, 2) overstory land that is infested, and 3) clean land. Included in this characterization should be the use of hand held spectroradiometry to identify ground signatures.

5. Develop new GIS map of the Park in five years depending upon advancements in remote sensing and GIS technology. There should be significant advancement in technology before another aerial map is produced.

6. Information is needed on leafy spurge patch sizes to help define priorities and types of treatments. Patches that are fragmented may require different treatment than those patches that have coalesced into larger groups.

7. The management of leafy spurge should include an examination of the ranges and preferred use areas of wildlife species in the Park, along with a review of the literature on the food habits of these ungulates. For example, although graminoids constitute the majority of bison forage, these animals do consume small amounts of forbs which increase forage quality. Therefore, the impact of herbicide treatments that remove all forbs needs to be evaluated, and alternatives suggested. Further, leafy spurge management techniques that remove woody vegetation impact white-tailed deer winter forage. Although the need to control leafy spurge appears paramount in light of the magnitude of infestation and the adverse impact it has on native vegetation, proposed techniques need to be carefully evaluated relative to other components of the ecosystem. Techniques that remove vast acreages of communities such as woody draws, but leave areas open to re-infestation of leafy spurge may pose immense problems for the continued survival of native wildlife species.

8. The management of leafy spurge should also include an examination of the distribution of rare plants and animals of the Park. Biological control and other techniques that

are highly selective for leafy spurge should be used in areas where the occurrence of rare forbs is documented.

9. Weed management areas should be established to help prioritize treatment. Weed management areas are discussed in the following section.

10. Need to develop a specific plan to communicate with the public and the hierarchy within NPS for public education, political action, and agency support and awareness. The following should be considered:

- Develop displays for the visitor center to communicate information about leafy spurge (e.g. the problem, the control methods being used, and the successes and failures).
- Develop press releases and brochures.
- Develop broad-based constituency support to obtain legislative funding.
- Use Weed Innovation Network (WIN) grant program (grass roots support) to help convince agencies, public, and political groups as to the seriousness of the problem and the need for money.

11. Take preventative action with horses brought into the Park by visitors. Hold horses for 24 hours to allow passage of seed of undesirable species and establish specific camping regulations concerning the containment of horses at camp sites. Do not allow importation of hay into the Park, only pelleted feed should be allowed. Establish a "sacrifice area" where horse trailers are parked. Vigorously control weeds in this area.

Educate public and employees about weed transmission and strongly enforce policy of no flower picking in the Park.

12. Every effort should be made to maintain biological diversity while treating leafy spurge. The first priority in areas of rare plants is to select treatment methods that are highly selective for leafy spurge and will not affect the rare plant. Treatments that could potentially harm a threatened or endangered species should not be used.

15. There are no areas in the Park that are considered too sensitive to treat for leafy spurge control. Methods can be developed to treat all areas.

Recommendations by Drainage Basins within the South Unit

The remote sensing and GIS work conducted by USDA for TRNP resulted in the development of a map of the Park that delineates the major drainage basins and quantifies the level of leafy spurge infestation for each basin. Three drainage basins were selected (numbers 2, 3, and 10) that represent heavy, moderate, and low infestation (Figures 2 and 3). Drainage basin #10 has heavy leafy spurge infestation, #2 has moderate infestation, and #3 has low infestation. The following recommendations from the panel are specific to each of these three categories of infestation and can be applied to all of the drainage basins in the Park.

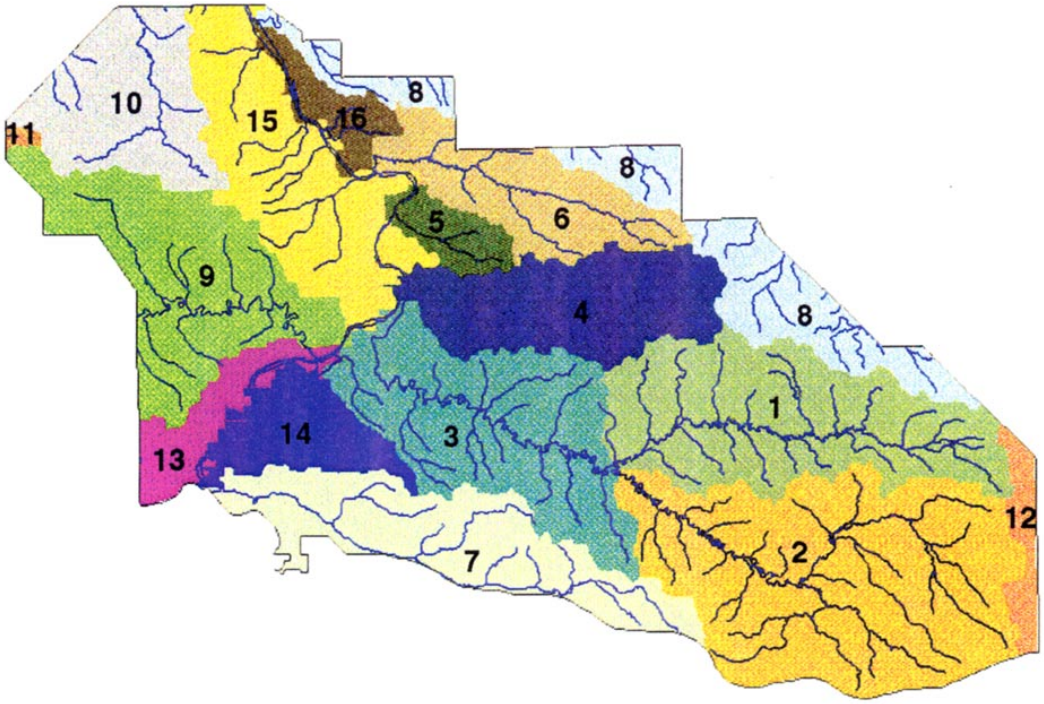

Figure 2. Watershed sub-basin map developed from the USGS Digital Elevation Model (DEM) data.

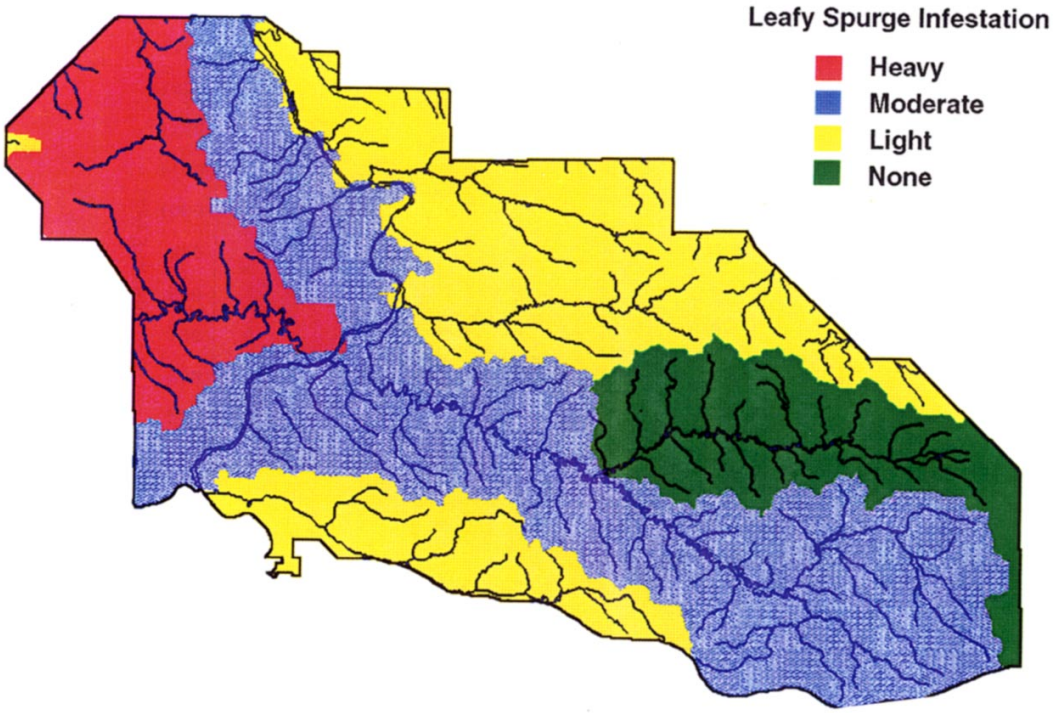

Figure 3. General breakdown of leafy spurge infestation by watershed sub-basin. Heavy (>5%, red), moderate (1-<5%, blue), light (>0 but <1%, yellow), and none infested areas (green).

Areas of heavy infestation (Drainage Basin #10)

Each drainage basin is divided into three physiographic units for treatment recommendations: 1) bottomlands, 2) woody draws, and 3) uplands. The recommendations represent a consensus among panel members as being the best treatment approaches using currently available technology.

Bottomlands. Highly infested bottomlands should be treated with a combination of biological control and herbicides. The perimeter of the infested areas should be alternately treated with a picloram + 2,4-D mix and glyphosate + 2,4-D. Treatment should begin with glyphosate + 2,4-D and then alternate every other year between picloram plus 2,4-D and glyphosate + 2,4-D. This treatment should be done by helicopter, treating one boom length along the perimeter and far enough out on the perimeter to treat the leading edge of the infestation.

In addition to chemical control, highly infested bottomlands should have biological releases of black flea beetles (*Aphthona czwalinae*), with some consideration given to copper spurge beetles (*A. flava*) and crown borers (*Oberea erythrocephala*), if available. Black dot spurge beetles (*A. nigriscutis*) should be established in side drainages between the bottomland and upland sites.

Woody Draws. Perimeter spraying of herbicides in woody draws is not recommended unless the spraying can be done outside of the drip line of trees without affecting the woody vegetation. The leafy spurge gall midge (*Spurgia esulae*) is recommended for woody draws because of its effectiveness in habitats of low sunlight. There may be pathogens available for use in this habitat, but extensive testing will be required before any releases are made.

In addition to the use of *Spurgia esulae*, *we* recommend that *A. nigriscutis* be used in combination with burning. Fall burning should be used as a pre-treatment and *A. nigriscutis* released into the site the following summer.

In general, the panel recommends that the use of goats or sheep be explored if the issue of disease transmission and other concerns can be resolved in a satisfactory manner. If these concerns cannot be resolved, we recommend that domestic animals not be used as a control agent at this time.

Uplands. The panel recommends spraying the perimeters of highly infested upland sites. On highly erodable sites we recommend that an every other year rotation of glyphosate + 2,4-D and 2,4-D alone be used, and on sites of low erosion potential that the chemical treatment alternate between glyphosate + 2,4-D and picloram + 2,4-D. Biocontrol should include the use of *A. nigriscutis* as the primary control method.

Areas of moderate infestation (Drainage Basin #2)

Bottomlands. Small isolated patches of leafy spurge in bottomlands should be aerially sprayed at the maximum labeled rate using 2 lb a.e./gallon formulation of picloram. These sites should be sprayed for one year and then observed over an 18-month to two year period. If follow-up treatment is needed after this time period, then the site should be aerially treated with picloram at 1 lb/A. Sites that are sprayed should be flagged, located

with GPS, and photographed following the first spraying for documentation and relocation.

Larger sites of moderate infestation should be sprayed in alternate years with glyphosate + 2,4-D (54 oz of product/A) and picloram + 2,4-D. Those areas of high infestation should be treated in a similar fashion as recommended for Drainage Basin #10. The perimeter should be aerially treated in alternate years with glyphosate + 2,4-D the first year, followed by picloram + 2,4-D the second year. In addition to the chemical control, highly infested bottomlands should have biological releases of black flea beetles (*Aphthona czwalinae*), with some consideration given to copper flea beetles (*A. flava*) and crown borers (*Oberea erythrocephala*), if available. Black dot spurge beetles (*A. nigriscutis*) should be established in side drainages between the bottomland and upland sites.

Woody Draws. The approach recommended for woody draws in Drainage Basin #10 should be used for treating leafy spurge found in areas of moderate infestation. The primary focus of any spraying program should be to contain leafy spurge and prevent its spread into unaffected areas. The use of pack horses and hand spraying in areas of low accessibility are recommended.

Uplands. The recommendations for treating leafy spurge in upland sites of moderate infestation include herbicide application and biological control. Small patches of leafy spurge should be aerially sprayed wherever possible and hand sprayed in those areas missed from the air. Aerial treatment in Drainage Basin #3 should begin along the south boundary of the Park and the flight path for treatment should be east and west. In addition, *A. nigriscutis* should be established at headwaters of sites with the heaviest infestation of leafy spurge.

Areas of low infestation (Drainage Basin #3)

Bottomlands. Bottomlands in low infestation areas should include perimeter spraying by air and hand spraying of small patches of spurge of low density. If areas of heavy infestation exist, these sites should be treated with *A. czwalinae*. The panel does not recommend release of insects in areas of low infestation.

Woody Draws. Areas in woody draws of low infestation should be hand sprayed. No other treatment is recommended.

Uplands. The recommendation for treating leafy spurge in upland sites of low infestation include herbicide application only. Small patches of leafy spurge should be aerially sprayed whenever possible; those areas missed from the air should be hand sprayed.

Overall recommendations

The management of lands in TRNP should be organized by topographic units and levels of leafy spurge infestation. Those areas of non-spurge infestation should be kept clean, those areas of low infestation should be treated intensively to remove leafy spurge, areas of moderate infestation should receive perimeter treatment to prevent the spread of

leafy spurge, and heavily infested areas should be the highest priority for biocontrol treatment.

In addition to direct treatment of leafy spurge, TRNP should develop a working GIS system within the Park. This system would be critical to the development and implementation of the leafy spurge management plan, for educating the public, and securing public and financial support for leafy spurge control. More specifically, the use of GIS maps will assist in making both short and long-term management decisions for implementing control strategies, provide easy access to current monitoring data, and provide a valuable education tool when sharing information with surrounding land owners.

The following recommendations should be considered when implementing an integrated management plan for leafy spurge.

1. Areas that are free of leafy spurge should be maintained in that condition, lightly infested areas should be targeted for intense herbicide treatment to remove leafy spurge, moderately infested areas should receive perimeter spraying to prevent further spread in combination with insect releases, and heavily infested areas should receive perimeter spraying and biocontrol.
2. The priority of spraying infested areas is as follows: 1) perimeter spraying of large patches, 2) spraying entire small patches, and 3) spraying large dense areas.
3. The chemical control program should be viewed as a short-term containment approach until biocontrol and other methods are more fully developed. The Park should beware of the impact of non-selective herbicides on non-target plants, and the potential impact on native animals. Critical habitats such as woody draws, and areas supporting rare plants should not be sprayed.
4. In areas where ground water contamination is a concern (i.e. groundwater depth is within 10 feet of surface), herbicide treatment should alternate yearly between glyphosate + 2,4-D and 2,4-D alone. Picloram should only be used in areas where ground water contamination is not a concern.
5. In heavily infested areas, insect releases should be at the headwaters of the drainage.
6. Population build up is a first priority of insect releases. TRNP should work towards increasing insect populations in order to make collections for redistribution. New insectary sites for *A. nigriscutis* should be established in upland sites with high infestations of leafy spurge. In addition, the ox-bow area across from Wind Canyon would be another potential site for the release of *A. nigriscutis*.
8. Develop an in-park GIS system to assist in management decisions and to solicit public and financial support for leafy spurge control.
9. A specific plan needs to be developed to communicate with the public and within NPS for public education, political action, and agency support.

Appendix

Effects of biocontrol agents on native *Euphorbia* species

P.C. QUIMBY, JR.[1], R.W. PEMBERTON[2], and J.L. BIRDSALL[1]

[1]*USDA-ARS Range Weeds and Cereals Res. Unit, Bozeman, MT.* [2]*USDA-ARS Aquatic Weed Research Lab., Fort Lauderdale, FL.*

The question of interactions among biological control agents for leafy spurge (*Euphorbia esula* L.) and native *Euphorbia* species was first addressed at the 1984 International Symposium on Biological Control of Weeds (Pemberton, 1985). At the time this analysis was presented nearly ten years ago, the clientele of the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) was desperate for biological control of leafy spurge. This analysis allowed biological control efforts to move ahead with consideration being given to threatened and endangered *Euphorbia* species in the United States along with attention to efficacy toward control of the target weed leafy spurge.

Native Euphorbiaceae of concern totaled 113 species (Op. cit.). Out of this total of 113 species, 32, species are in the same subgenus (Esula) as leafy spurge; then of the 32 species in the subgenus Esula, 20 species are in the same section (*esula*) as leafy spurge. Nine of the eleven rare *Euphorbia* species under review at that time (1984) for federal protection as threatened or endangered are in the subgenus Chamaesyce; two (*E. purpurea* and *E. telephiodes*) are in the subgenus Esula. These rare species all occur in the eastern seaboard or in the southern latitudes of the United States. It was theorized that some of the native spurges sympatric with leafy spurge could bridge biocontrol agents to the rare species if the agents could live in these different climatic zones. The "bridge" theory is somewhat controversial and, since it has not been known to occur, has not always been considered in petitions for release or environmental assessments submitted to the Animal and Plant Health Inspection Service. In practicality, biocontrol agents more fitted to the environment of the northern latitudes of Canada and the Northern Plains are not likely to provide problems for rare spurges in the Southern United States (Harris - personal communication).

What does all of this mean with respect to using biological control as technology against leafy spurge in the Theodore Roosevelt National Park in North Dakota?

1. There are no *Euphorbia* species in the Northwest-Rocky Mountains-Northern Great Plains Region that are listed or under review for federal protection.

2. *Euphorbia robusta* (Engelm.) Small, subgenus Esula, section esula, has been identified as a "critically imperiled" native plant species in Theodore Roosevelt National Park and the state of North Dakota (Heidel, 1990).

3. Of the native species of *Euphorbia* in the subgenus Esula, only *E. robusta* and *E. spatulata* occur in the Soil Conservation Service's Region 4 (Eastern MT, Eastern WY, ND, and SD). *Euphorbia spatulata* is placed in another section (*galarrhoei*) so is less closely related to leafy spurge than is *E. robusta.* Moreover, *E. spatulata is* an annual

while *E. robusta* is a perennial. In general, most of the biological control agents, especially the univoltine - one generation per year - root feeders, will require perennials for development.

4. Most of the biological control agents released in North America to date were first released in Canada (*Hyles euphorbiae*, *Chamesphecia tenthrediniformis*, *Chamesphecia hungarica*, *Oberea erythrocephala*, *Lobesia euphorbiana*, *Aphthona nigriscutis*, *A. flava*, *A. cyparissae*, *A. czwalinae*, and *A. lacertosa*) with limited attention to their host relationships to native United States spurges. Canada does not have rare species of spurge or species of concern. *Bayeria capitigena* (now divided to include the new species *Spurgia esula*) was first released in the United States and subsequently in Canada. *Dasineura* sp. near *capsulae* has not yet been released (Pemberton, 1994).

According to Pemberton (1985), *Hyles euphorbiae* appears to have a broad host range evidenced by acceptance of members of North American *Euphorbia* subgenera Esula (e.g. leafy spurge), Chamaesyce (e.g. *Euphorbia maculata*), and Agaloma (e.g. *Euphorbia marginata*) in host specificity testing. The moth *Hyles euphorbiae* was introduced to the United States but now exhibits a nuclear polyhedrosis virus (NPV) which prevents the buildup of significant populations (Rees - personal communication).

Chamesphecia tenthrediniformis, a clear-winged root-boring moth released for several years from 1970 on, failed to establish; its host range was too narrow in that the leafy spurge complex, which has apparently formed hybrids in North America, did not support development.

The root-boring moth *Chamesphecia hungarica*, first released in Canada, was cleared for release in the United States in 1993 and is scheduled to be released in 1994. This moth has a very narrow host range in that it attacked only one species in the subgenus Esula (*E. lathyris*) other than the target leafy spurge. The moth is adapted to moist habitats only and would not be expected to attack *E. robusta* which occurs only in dry sites.

Oberea erythrocephala, a root- and stem-boring cerambycid beetle, did not establish in Canada, but a 1983 release in the Yellowstone Valley near Columbus, MT (Rees *et al*., 1986) has established well as of 1993 (Rees - personal communication). This beetle is causing significant damage to leafy spurge in riparian zones and upland benches adjacent to the alluvial plain. *Oberea erythrocephala* was tested against four native spurges (subgenera Agaloma and Chamaesyce), none of which supported development; however, Pemberton (1985) states that insufficient testing was done to predict "the degree of use" of United States spurges.

Lobesia euphorbiana, a tip-webbing moth, has a wider host range; nine of eleven native spurges supported development. This moth was released in Canada in 1983 although its establishment was not confirmed in 1984 (Pemberton, 1985). No permits have been requested for release of *Lobesia euphorbiana* in the United States because it was not recommended by the Technical Advisory Group (TAG).

Most of the flea beetles in the genus *Aphthona* (*A. flava*, *A. cyparissiae*, *A. czwalinae*, and *A. nigriscutis*) were released in Canada before the United States. These beetles were subjected to host-range tests by the International Institute of Biological Control (IIBC) but were not generally tested by IIBC on *Euphorbia robusta* or other American species.

Before these species were released in the United States, they were tested by Pemberton in Albany, CA and in Bozeman, MT (*A. nigriscutis*) against United States spurges that represented different subgenera to allow more accurate predictions of the potential host ranges. Pemberton (11985) and Pemberton and Rees (1990) discuss some of the results. *Aphthona flava* was tested against fourteen native spurges; four species in the subgenus Esula were acceptable laboratory hosts. The rare *Euphorbia purpurea* and *E. telephiodes* (subgenus Esula) were not accepted by *Aphthona flava.* Fornasari (after reviewing Pemberton's published and unpublished work presented in petitions for release) stated (personal communication) that *A. flava*, *A. czwalinae*, and *A. cyparissiae* "showed significant adult feeding, oviposition, longevity, and larval development on *Euphorbia robusta* and other American species."

It should be noted that *Aphthona nigriscutis* was not approved by the USDA Animal and Plant Health Inspection Service (APHIS) for release in the United States without further testing by ARS beyond what had been done by IIBC before its release in Canada. Although this biocontrol agent was expanding rapidly in Manitoba in 1989 after releases in 1983/84 and would theoretically soon move south of the Canada/United States border on its own, further testing was required by APHIS as a condition for approval to release *A. nigriscutis* in 1989 in the United States. The results of the ARS testing by Pemberton in Bozeman indicated *A. nigriscutis* may be narrower in host range than *A. flava. Euphorbia robusta* was not available for these tests. Nevertheless, one could expect *E. robusta* to be potentially a host and support development of the flea beetle species (note: the host range testing data in the petitions for release submitted by ARS to APHIS are available from ARS Biological Control Documentation Center).

Aphthona lacertosa, already released in Canada, was released for the first time in the United States in 1993. The host range of *A. lacertosa* is limited to only a few species in the subgenus *Esula* and is similar to the host range of *A. nigriscutis.* While this host range is more narrow than that of *A. flava*, in the absence of actual testing, *Euphorbia robusta* must be considered a putative host.

Spurgia esula (new species now separated from *Bayeria capitigena*), a shoot tip gall midge, completed development on four (of eleven) species native to the United States in the subgenus Esula (Pemberton, 1985). Since this midge completed development on perennials and annuals, it will likely be able to use *Euphorbia robusta.*

Dasineura sp. near *capsulae* is another midge species restricted to the flowerheads of species in the subgenus Esula. Only one of four native spurges (*E. incisa*) served as a host. *Euphorbia robusta* was not tested and, therefore, is a putative host. *Dasineura* sp. near *capsulae* is cleared and scheduled for release in the United States in 1994.

Permission was recently granted (1993) by APHIS to release *Aphthona abdominalis* in the United States (after review of the ARS petition and Environmental Assessment by the Technical Advisory Group which includes Canadian representatives). Testing by ARS in Europe on *A. abdominalis* indicated this flea beetle is restricted to the subgenus Esula in the field. It was tested on one North American species in the subgenus Esula, the annual *E. spatulata*; this species did not support development of larvae to adults. *Euphorbia robusta*, *E. telephoides*, and *E. purpurea* were not tested. Based on its known host range and the results from other *Aphthona* species, it is very likely *E. robusta* could

be a host. Recent host range tests by ARS in Bozeman indicated that a Chinese spurge flea beetle (*Aphthona chinchihi*) accepted *Euphorbia robusta.* Further testing in the laboratory will be required.

5. Our conclusion, based on our rather cursory analysis, is that *Euphorbia robusta* is very likely to be used and possibly damaged to an unknown extent in the field by most of the biological control agents for leafy spurge already released (with approval of APHIS) in the United States. Given the close relationship of *E. robusta* to leafy spurge and the results from limited host-range tests done with this plant species to date, this is to be expected.

Euphorbia robusta is not rare from a regional standpoint and is widely distributed. It is more abundant in the more southern latitudes of the Northern Plains and Intermountain Region, e.g. in Wyoming. Many, even most, of the populations are not likely to be sympatric to leafy spurge which still has a spotty, disjunct distribution. Many isolated stands of *E. robusta* should escape most if not all of the biological control agents released against leafy spurge. However, in Theodore Roosevelt National Park the proximity of the *E. robusta* to large stands of leafy spurge puts the native species at risk when large populations of biocontrolling insects build up on the adjacent leafy spurge and potentially begin to spill over onto *E. robusta.* The magnitude of this risk is unknown but in the worst case could be mitigated by replanting *E. robusta* after the leafy spurge/biocontrol agent oscillations dampen to low ebb.

In complex natural environments, populations of plant species and their specialist herbivores rise and fall, without the loss of either. There is no evidence of eradication of a plant population by an insect herbivore. Density dependence relationships ultimately prevail. Host preference then plays a role and should be the subject of an intensive investigation in Theodore Roosevelt National Park. Laboratory host testing tends to overestimate actual effects in the field, which are at present unknown.

6. Biological control is one technological component in integrated weed management systems. It is not risk free – as with other strategies, the risks and benefits have to be weighed. Leafy spurge is a weed very damaging to ecosystems and is itself a threat to rare, herbaceous plant species. Leafy spurge is extremely difficult to control and no strategy is completely risk free. Biological control, if successful, appears to us to be the best method for suppressing leafy spurge populations with a minimum of environmental damage in the Park and with a minimum effect on nontarget species, *E. robusta* notwithstanding. Because leafy spurge is a dynamic invasive weed, it is virtually impossible to control with static systems. In our opinion, a dynamic control system, i.e. biological control, is indicated as a major strategy in an integrated weed management system. Park managers will ultimately have to make the decisions on how to proceed to manage the problem of leafy spurge in Theodore Roosevelt National Park.

Table 1. *Euphorbia robusta* as a host of European/Eurasian leafy spurge biocontrol agents approved for introduction to North America.

Biocontrol Agent	Tested *E. robusta* = laboratory host	Untested *E. robusta* = putative host
Aphthona abdominalis		+
Aphthona chinchihi[1]	+	
Aphthona cyparissiae	+	
Aphthona czwalinae	+	
Aphthona flava	+	
Aphthona lacertosa		+
Aphthona nigriscutis		+
Chamesphecia hungarica[2]		–
Chamesphecia tenthrediniformis[3]		–
Dasineura sp. near *capsulae*		+
Hyles euphorbiana[4]		+
Lobesia euphorbiana[5]		+
Oberea erythrocephala		+
Spurgia esula		+

[1]Not yet approved for release in U.S. Fed heavily on E. *robusta* in lab tests. Further tests needed on development.

[2] Narrow host range and adapted to moist habitats.

[3] Not established on leafy spurge due to narrow host range.

[4] Infected with NPV which limits populations.

[5] Permit for release in U.S not requested. Very wide host range.

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Acknowledgements

Theodore Roosevelt National Park Staff expresses its appreciation to members of the Leafy Spurge Advisory Panel.

Special thanks to Dr. Edward Redente, Colorado State University for consolidating and editing the comments of the Panel.

Illustration by Tamara Sayre.

Geographic Information System Maps by Dr. Gerry Anderson, USDA-ARS Remote Sensing Research Unit.

Printing cost underwritten by the Rocky Mountain Elk Foundation.

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